Combined Source–Channel Coding for the Transmission of Still Images over a Code Division Multiple Access (CDMA) Channel

E. V. H. Iun, *Member, IEEE*, and A. K. Khandani

***Abstract*— This letter considers a combined source-channel coding scheme for image transmission over the uplink of a wireless IS-95 code division multiple access (CDMA) channel using discrete cosine transform. By adjusting the dimension of the orthogonal signaling scheme, we trade the system error-correction capability for a faster bit rate. The increase in channel error is relieved by employing a set of quantizers which are designed using a joint source–channel optimization algorithm.**

***Index Terms*— CDMA link, channel optimized quantization, discrete cosine transform.**

I. Introduction

THIS letter studies the use of a combined source–channel coding scheme for the transmission of still images over the uplink[1] of the IS-95 cellular radio code division multiple access (CDMA) system using discrete cosine transform (DCT). We consider an enhanced version of the IS-95 as used in [1]. We make use of a channel optimized quantization scheme, and sacrifice error-protecting redundancy in the channel coding for more accurate quantization (by lowering the dimension of the orthogonal signal set used in the IS-95). The bit allocation problem of the quantizer array is solved by using a new approach based on the integer programming technique. Without bandwidth expansion, our proposed scheme results in an improvement in the reconstructed image quality, especially for good channel conditions.

References [2] consider the problem of combined source–channel coding for the transmission of still images. In [3], Farvardin and Vaishampayan provide an algorithm for minimizing total distortion caused by the quantization and channel noise. Later, the same researchers present a method for the joint source–channel coding of a scheme based on the two-dimensional block cosine transform for a Gaussian source over a memoryless binary symmetric channel [4].

Manuscript received May 28, 1997. This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Information Technology Research Centre (ITRC). This work will be presented in ICC'97. The associate editor coordinating the review of this letter and approving it for publication was Dr. M. Z. Zoltowski.

The authors are with the Department Electrical and Computer Engineering, University of Waterloo, Waterloo, Ont. N2L 3G1, Canada.

Publisher Item Identifier S 1089-7798(98)04735-8.

[1]Uplink (or reverse link) refers to the transmission from a mobile to the base station.

II. System Overview

The block diagram of the system under consideration is depicted in Fig. 1. The "8×8" blocks of the image are transformed using a two-dimensional (2-D) DCT. The transformed coefficients are quantized by a set of 8×8 quantizer banks. The quantizer outputs are labeled using the natural binary code. The output of the source encoder is coded by a rate 1/3 convolutional code. The convolutional encoder has a constraint length of 9, with the generating functions $\{557, 663, 711\}$ octal as adopted by the IS-95 standard. The output bits of the convolutional encoder are mapped to the points of an M-dimensional orthogonal signal set based on the Hadamard code-words. The IS-95 standard specifies M to be 64. The constituent bit rate of each Hadamard code-word is fixed at 307.2 kb/s. This gives the 64-ary signaling of the IS-95 system the required bit rate of 9.6 kb/s.

The proposed combined source–channel coding involves: 1) changing the value M in orthogonal signaling (to trade-off the performance of the channel coder for a better source coder); 2) optimizing the quantizer thresholds and the reconstruction values (to incorporate the effect of the channel errors); and 3) generating a bit assignment (which incorporates the effect of the channel errors) using integer programming. We assume that M is a power of 2, i.e., $M = 2^n$, where n is the number of bits represented by each of the orthogonal signals. We select $M = \{2, 4, 8, 16, 32, 64\}$, corresponding to $n = \{1, 2, 3, 4, 5, 6\}$, respectively. The design of the channel optimized quantizer is based on the principles explained in [3].

Microcellular applications at a carrier frequency of 2 GHz are of interest in this work. We consider slowly fading channels with a Doppler frequency of 2 Hz, which corresponds approximately to a portable speed of 1 km/h [5]. Given that the Doppler shift is much smaller than both the carrier frequency and the bit rate, we have a flat-fading channel. Hence, we select a popular Rayleigh flat-fading channel as our model. Also, we have selected the widely popular Jakes' model as given in [6] to define the power spectrum of the channel.

We assume that the base station employs a two-antenna diversity. With uncorrelated received signals, our setup represents the mobile radio channel as two independent Rayleigh flat-fading paths. The combined effect of the other channel imperfections is modeled by an additive white Gaussian noise (AWGN) source.

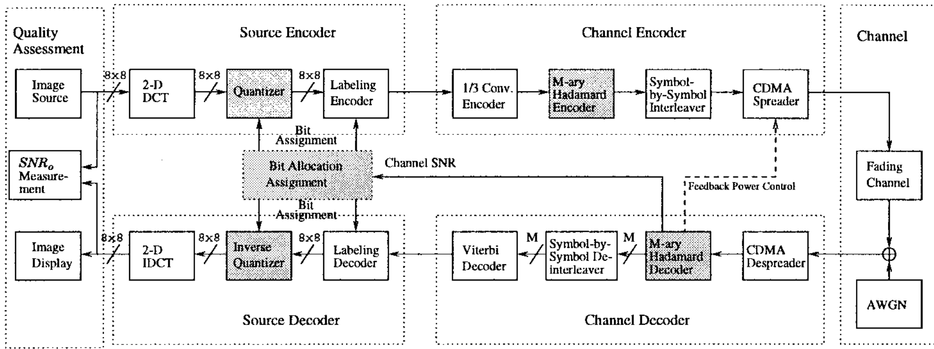

Fig. 1. System overview.

The M-ary waveforms are symbol-by-symbol interleaved to combat channel fading. We use an interleaver span of 20 ms [7] for all values of M. The interleaver output bits are spread and transmitted through the radio channel. The chip rate chosen is 1.2288×10^6 chips/s. This means that each constituent bit of the Hadamard code-words is spread by four chips as used in [5]. At the receiver, the output of the Hadamard correlators from the two diversity branches are square-law combined (weighted with equal gains). These M correlation results are deinterleaved and used as the metric to a soft decision Viterbi decoder. The low-rate return downlink[2] serves as a feedback in the close-loop power control. We assume that this channel has a crossover probability of 5×10^{-3}.

In the process of changing M, it may happen that $\log_2 M$ is not a multiple of 3. This situation results in a mismatch with the rate 1/3 convolutional encoder. We deal with this problem by merging an appropriate number of subsequent trellis stages together.

III. Bit Allocation Using Integer Programming

Consider the quantization of K random variables, say $X^0, X^1, \cdots, X^{K-1}$. Define the normalized quantizer rate-distortion function, $W_i(b_i)$ as the mean square error incurred in quantizing X^i with b_i bits. A multiplicative factor G_i accompanies $W_i(b_i)$ to incorporate the effect of the input variance. We use a set of binary variables $\delta_i(j)$ to specify the integer bit allocated. We set,

$$\delta_i(j) = \begin{cases} 1, & \text{if } j \text{ bits are allocated to quantizer } i, \\ 0, & \text{otherwise.} \end{cases}$$

Using these variables, the bit allocation vector $\vec{\boldsymbol{b}} = (b_0, b_1, \cdots, b_{K-1})$ is computed using

$$\begin{cases} \text{Minimize: } D = \sum_{i=0}^{K-1} \sum_{j=p_i}^{q_i} \delta_i(j) G_i W_i(j) \\ \text{subject to: } \sum_{j=p_i}^{q_i} \delta_i(j) = 1, \quad \forall i \in \{0, \cdots, K-1\} \\ \sum_{i=0}^{K-1} \sum_{j=p_i}^{q_i} j\delta_i(j) \le B, \delta_i(j) \in \{0,1\}. \end{cases} \tag{1}$$

[2]Downlink refers to the transmission from the base station to a mobile.

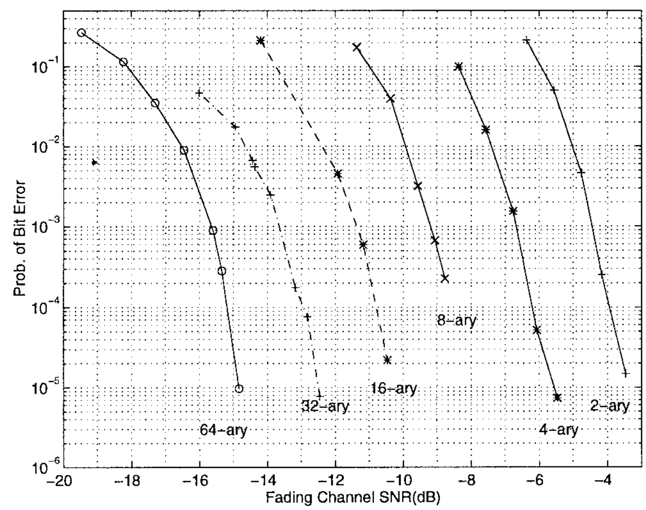

Fig. 2. BEP as a function of the channel SNR for different values of M.

where b_i's are integer, D is the overall distortion, B is the fixed quota of available bits, and p_i, q_i determine the range of the admissible bit assignment for each quantizer. The optimization problem in (1) is solved using an application software called the General Algebraic Modeling System (GAMS) version 2.25.

The conventional methods of bit allocation are based on approximating the integer valued bits by real numbers, and/or making so me assumptions (for example, on the convexity) of the quantizer rate-distortion function. The proposed Inter-Programming (IP) method avoids these shortcomings, and computes the optimum bit allocation without making any extra assumption.

IV. Numerical Results

We define the channel signal-to-noise ratio (SNR) as the ratio of the average faded signal power to the received noise. Fig. 2 shows the bit-error probability (BEP) for six values of M as a function of the channel SNR.

For a particular value of M and channel SNR of interest, we first find out the expected BER from Fig. 2. We then select a quantizer designed for the closest bit error rate, and make use of the corresponding bit allocation table as computed earlier.

The output SNR, (SNR_o), compares the mean square error between the original image (gray levels of 8 bits/pixel) and

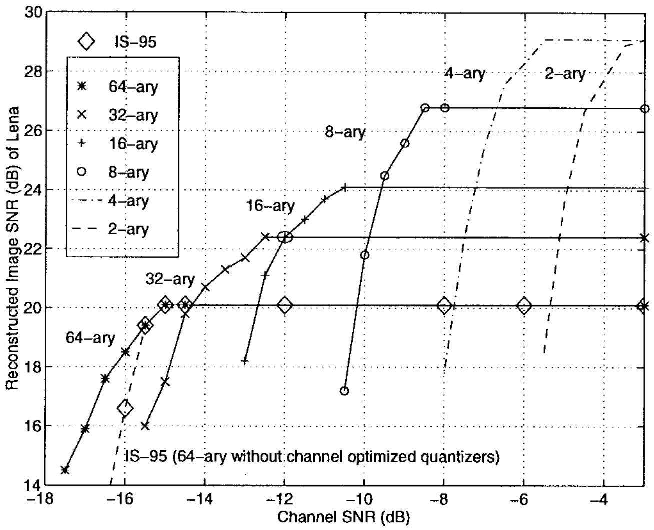

Fig. 3. Reconstructed image SNR_o versus channel SNR.

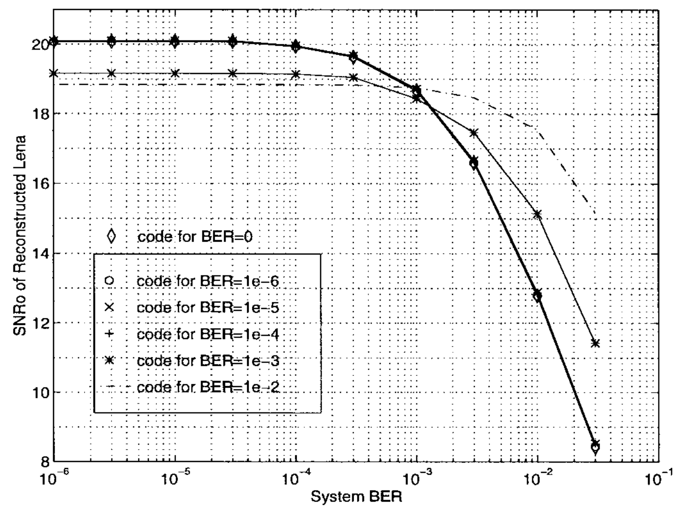

Fig. 4. The effect of the channel mismatch on the SNR_0, $M = 64$. NBC with 30 b/subframes for 64-ary signaling.

its reproduction at the receiver. Fig. 3 shows the output SNR_o versus the channel SNR for a Lena image. Several general characteristics are noticeable. First, note the sharp threshold effect which becomes more pronounced as the dimension M decreases. This is because the smaller the M, the bigger is the SNR_o discrepancy between an error free channel and a noisy channel. Secondly, for channel SNR in excess of a threshold point, channel errors are rare and the performance is limited solely by the quantization noise. This counts for the flat portion of the curves.

Fig. 3 shows that our 64-ary system (with matching channel optimized quantizers) performs better than the ordinary IS-95 system (whose quantizer structure ignores the effect of channel noise). The difference is prominent for low system BER (around 1.0×10^{-3}).

Fig. 4 show the effect of the channel mismatch on the reconstructed image SNR_o for 64-ary signaling. Similar results for other values of M can be found in [8]. Note that the comparison with the curve corresponding to zero error probability indicates the gain obtained through the use of the combined source-channel coding method.

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